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Tidal Streams around External Galaxies

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Abstract. We have the unique opportunity to observe and model nearby streams around the two large Local Group spirals Milky Way and M31 in great detail. However, the detection of streams around other external galaxies is required to verify the general application of the derived results. We give a short summary of streams around other galaxies known in the literature, measuring for the first time the surface brightness of Malin's M 83 stream with modern CCD imaging. In addition, we present four new detections of possible stellar streams around disk galaxies.

1. Introduction

Hierarchical clustering scenarios of galaxy formation, such as cold dark matter-dominated cosmologies, predict that structure forms first on small scales and later combines to form larger galaxies. Low-mass objects similar to dwarf galaxies are supposed to be the building blocks and should have formed prior to the epoch of giant galaxy formation. Later they merge to build the larger galaxies. In this context, the accretion and tidal disruption of dwarf galaxies would play an important role in the evolution of galaxy halos and is essential for understanding the stellar mass assembly of large spiral galaxies. Minor mergers (satellites with about $1/10\ M_{\rm parent}$) will significantly affect the star-formation and further evolution of disk galaxies, e.g. by inducing disk thickening, warping, or bar formation. Even smaller minor mergers, so called "miniscule" mergers (Ibata 2001), with dwarf galaxies of lower mass should frequently happen to every large spiral galaxy. This accretion of low-mass systems, as a natural consequence of the merging history of a galaxy, is still ongoing and should give rise to long *stellar streams* (Johnston et al. 1996) around the parent galaxies.

2. Known Stellar Streams and Open Questions

The Local Group is the natural place to start looking for streams and the discovery of the prior unknown Sagittarius dwarf galaxy (Ibata et al. 1994) revealed a close satellite of the Milky Way confirmed to be caught in the act of tidal destruction by means of star counts and kinematics. In addition, Ibata et al. (2001) detected another giant stellar stream within M31's (Andromeda Galaxy) halo. The Sgr and And stream support the scenario of "spaghetti halos" (Morrison

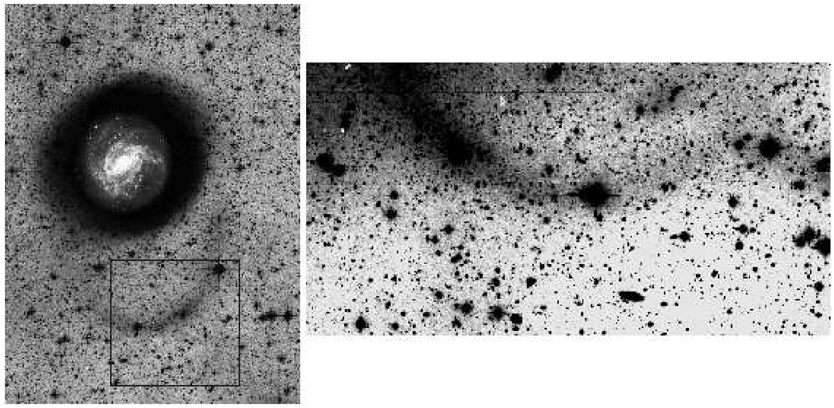

Figure 1. M 83: *Left image* taken from Malin & Hadley (1997). *Right image* is a CCD exposure of the stream with the INT/WFC. The box on the left marks approximately the position of the CCD chip.

et al. 2000): Galaxy halos build up by accumulation of tidally disrupted dwarf galaxies. But are tidal streams really common around galaxies? Only a few detections of possible streams in external galaxies have been made. Taking into account that Sgr viewed from outside would have a surface brightness of $\mu_{\mathrm{V}} = 31\mathrm{mag}/\square''$, this is not difficult to understand. The first examples of extragalactic tidal streams are shown in the paper by Malin & Hadly (1997). Using special contrast enhancement techniques they were able to highlight faint structures around nearby galaxies of large angular size on deep photographic plates. From this paper M 83 (cf. Fig. 1) is probably one of the best cases, but structures in M 104 (Sombrero) and NGC 2855 may also represent stellar streams. Perhaps the most compelling example found to date is an elliptical loop, 45 kpc in diameter, around the nearby, late-type, edge-on galaxy NGC 5907 by Shang et al. (1998). Recent discoveries include Peng et al.'s (2002) detection of a stellar stream in the envelope of the giant elliptical galaxy NGC 5128 (CenA), and a fine example in the HST/ACS commissioning data which nicely shows that UGC 10214's long tail is produced by tidal disruption of an in-falling dwarf galaxy.

The discovery of these extragalactic tidal streams evoke a number of questions: Are they exceptional cases or are tidal streams around galaxies really as common as predicted by current models? Are these examples typical of the appearance of such streams? What can we learn from these streams? What are the possibilities to find more of them? The latter question is addressed nicely by Johnston et al. (2001), who estimate typical surface brightnesses of streams around external galaxies from semianalytic modelling. For one of their $10^8\,M_{\odot}$ model satellites the stream starts with surface brightness $\mu_{\mathrm{R}} \approx 26.0\,\mathrm{mag}/\square''$ and, by spreading stripped material along its orbit, decreases to $28.5\,\mathrm{mag}/\square''$ after 1 Gyr and down to $30.0\,\mathrm{mag}/\square''$ after 4 Gyr . Systematic searches for more extragalactic tidal streams, in addition to providing evidence for the miniscule merger scenario, would hopefully turn up more examples of geometrically simple cases like NGC 5907 for which comparison to models like those of Johnston et al. (2001) would yield reliable estimates of progenitor mass and age.

3. New Streams and Outlook

What methods can be used to detect extragalactic streams? While previous discoveries have been serendipitous, the natural approach would be a deep survey of edge-on spiral galaxies in order to geometrically maximize the detection probability. This could be done either for nearby, large angular sized galaxies with the currently available wide-field imaging devices or for more distant samples using single CCD devices. Though the influence of the $(1+z)^4$ cosmological surface brightness dimming for galaxies out to 100 Mpc will be negligible — only 0.1 mag — we have had little success with either approach: In a pilot survey using deep KPNO 0.9m MOSAIC images ($\mu^{\rm R}_{\rm lim} \approx 27\,{\rm mag}/\Box''$), we have not found indications for streams around the nearby edge-on disks NGC 3044, NGC 3079, and NGC 3432, and, surprisingly, in a deep ($\mu^{\rm V}_{\rm lim} \approx 26-27\,{\rm mag}/\Box''$) imaging sample of ≈ 80 more distant, edge-on disk galaxies (Pohlen 2001) we have found only one clear example (ESO 572-044) of a minor merger stream (two additional galaxies — NGC 5170 and ESO 286-018 — show clear tidal features but are probably connected to more similar mass sized companions). Meanwhile, we have had better success searching publicly available, deep, wide-field surveys. Though not typically centered on nearby spiral galaxies and the typically detected streams will tend to be at redshifts where the surface brightness dimming becomes important (e.g., for a redshift of $z=0.12$ the brightness already decreases by 0.5 mag), this technique has been used to find three of the four new stream candidates shown in Fig. 2:

ESO 572-044: This Sb galaxy (diameter: d=1.7′) is probably surrounded by a tidal stream. It is enclosed by an arc-like structure with a possible dwarf galaxy as the origin. ESO 572-044 exhibits a large thick outer disk at low surface brightness which may indicate a recent interaction with the similar-sized nearby spiral ESO 572-046 ($\Delta v_{\rm rad}$ = 150kms^{-1}). **PGC 1018343**: This small galaxy ($d \approx 25''$) was fortuitously found on a deep ING/WFC image. It is listed as NPM1G-07.0455 in NED and also detected in 2MASS, but has no measured redshift. The stream is clearly visible on the lower right side but also extends to the upper left side. **PGC 751050**: This edge-on S0 galaxy ($d \approx 25''$) is another serendipitous detection of a possible stream found in the ESO-WFI wide-field image of the Chandra Deep Field South. The stream is obvious and connected to a possible satellite at the end. It has a 2dF redshift of $z=0.1028$ and is listed in 2MASS as 2MASXi J0332467-274212. **S J160610.7+552700** : This spiral galaxy ($d \approx 20''$) with unknown distance lay by chance in the field of the HST image of the famous Tadpole galaxy taken during ACS commissioning. It also shows a stream extending on both sides.

We are in the process of collecting the missing redshifts and calibrated photometry that will allow a detailed comparison of these new detections with the Johnston et al. (2001) models. In addition, we are working with a deep, partly multi-colour, public survey of $10\,\Box^\circ$ from the Wide Field Camera at the ESO 2.2m telescope (kindly provided by M.Schirmer and T.Erben from Bonn University). This survey covers a set of random fields outside of any specific cluster, and therefore provides a suitable sample of isolated spiral galaxies at various redshifts to systematically search for tidal streams.

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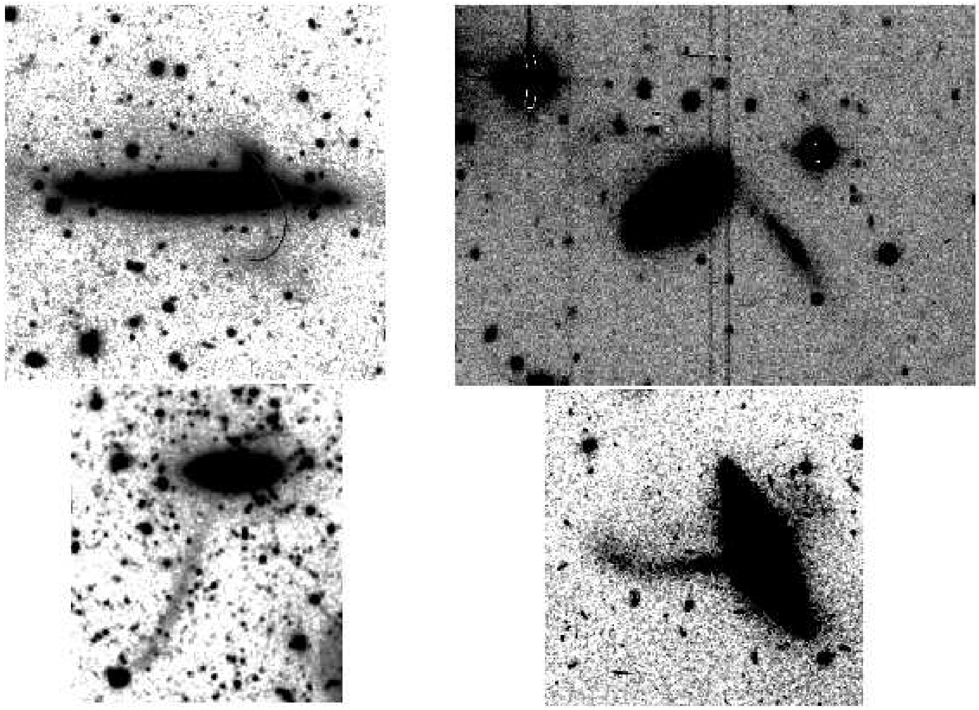

Figure 2. New streams: ESO 572-044, ESO 1.5D/DFOSC, 60 min, V-band image *(upper left panel)*; PGC 1018343, INT/WFC, 30 min, r *(upper right)*; PGC 751050, ESO/WFI, 17.8 hour, R *(lower left)*; S J160610.7+552700, HST/ACS, 134 min, $F606W$ *(lower right)*

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